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Westinghouse Electric Corporation
Astronuclear Laboratory

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February 23 To May 31, 1968

Quarterly Progress Report Phase I

CASCADED THERMOELECTRIC TEST GENERATOR

JPL CONTRACT 952196

NAS 7-100

Westinghouse Astronuclear Laboratory

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TECHNICAL CONTENT STATEMENT

This report contains information prepared by the Westinghouse Astronuclear Laboratory under JPL subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

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ABSTRACT

This report covers the work performed under JPL contract 952196 for the "Design and Fabrication of a Cascaded SiGe/PbTe Thermoelectric Test Generator" for the period February 23 to May 31, 1968. This effort is being performed in two phases: Phase I consists of a detailed design and analysis of the cascaded test generator, and Phase II consists of the fabrication and checkout testing of the system. The work reported herein covers the initial design of the cascaded test generator under Phase I. The system concept, preliminary system design, and performance estimates are presented. Detailed performance maps have been intentionally omitted in order to keep this document unclassified.

1.0 INTRODUCTION

A cascaded SiGe/tubular PbTe thermoelectric test generator is being designed and fabricated under contract to the Jet Propulsion Laboratory, Pasadena, California. This effort is being performed in two phases: Phase I includes the detailed design and analysis of the cascaded test generator and Phase II includes the fabrication and initial checkout testing of the system. This report covers the work performed during the first quarter of the contract effort under Phase I (February 23 to May 31, 1968). A brief discussion of the system concept, preliminary system design, and system performance estimates is presented. Detailed performance analyses have been intentionally omitted in order to avoid classification of this document. No conclusions or recommendations are presented since the design is only preliminary.

The concept of a cascaded SiGe/tubular PbTe thermoelectric test generator was the "outgrowth" of a contract (P. O. No. EQ - 389516) recently completed by Westinghouse for the Jet Propulsion Laboratory. This contract consisted of the design, analysis, fabrication, and checkout testing of an electrically heated heat pipe/tubular PbTe module/unidirectional space radiator power supply test system. The design of this system closely simulated an actual space power system; changes necessary for the space system would include the replacement of the electrical heater with a similar radioisotope heat source design and a weight optimization of the unidirectional radiator.

Checkout testing of the laboratory device indicated a measured overall efficiency of 5.5 percent. At present, the apparent temperature limit of the tubular module (1200-1300°F) is established at several hundred degrees below the temperature available from refractory metal isotope heat sources (2000°F) under development. Opportunity, therefore, exists to increase the system efficiency by adding a topping stage, able to utilize the full temperature capability of the heat source, between the isotope heat source and the tubular generator.

The cascaded concept was thus developed wherein a SiGe module would act as the topping stage. The mechanics of the cascaded test system would be as follows: (1) heat would be transferred by radiation from an electrical heater to the SiGe module where a portion would be converted to electrical power, (2) the heat pipe would act as the sink for the SiGe module and would transfer the waste heat in an isothermal fashion to the PbTe module, (3) the PbTe module would convert a portion of the heat supplied to electrical power, the remainder being removed by a calorimetric sink. The cascaded test system will operate in a vacuum to simulate actual space conditions. The design efficiency goal for the cascaded unit is 7 percent. This increase in efficiency is provided by the additional power output yielded by the SiGe module, while only a small increase in thermal energy is required over that necessary to power the PbTe module.

Progress Summary

During the period covered by the first quarter of this contract, the following items were accomplished:

1) Preliminary system performance estimates were established.

2) The electrical heater material and configuration were selected.

3) Preliminary designs of the SiGe module and the attachment of this module to the heat pipe were established.

4) The heat pipe, the PbTe tubular module, and the thermal coupling of the heat pipe to the tubular module were selected.

5) Preliminary design of the calorimeter to serve as the heat sink for the cascaded system was established.

2.0 TECHNICAL DISCUSSION

General

The cascaded thermoelectric test generator is similar in design to the heat pipe/tubular PbTe module system fabricated under JPL P. O. No. EQ - 389516. Design modifications include the replacement of the electrical heater with a SiGe module topping stage and a redesigned electrical heater to simulate radiation heat transfer from an isotope heat source, the replacement of the unidirectional radiator by a water calorimeter, and the operation of the system in a vacuum instead of in air. The design of the heat pipe, tubular PbTe module, and heat pipe/tubular module interface will be similar to the system previously fabricated.

A sodium heat pipe with a diameter of about 1 inch and a length of about 18 inches will act as the heat sink for the SiGe module and the heat source for the PbTe module. The length of the heat pipe may vary over that previously fabricated in order to accommodate the SiGe topping stage. The heat pipe will be thermally mated to the PbTe module, using a split boron nitride sleeve. Checkout tests of this mating concept indicate a radial temperature drop of less than 50°F across the BN sleeve. No changes are contemplated in the tubular module design; however, the method of mounting the tubular module will change. The mounting and support concept will be presented at a later date.

Prime emphasis during this quarter has been on the design of the SiGe topping stage, the design of the water calorimeter, the design of the electrical heater, and the establishment of preliminary system performance. These areas are briefly discussed in the following paragraphs.

Electrical Heater Design

Various general types of heaters and heater designs were considered for the cascaded application. A high current-low voltage heater of tantalum in the conventional split-tube vacuum application configuration was selected. This type of heater most nearly satisfies the requirements of this application which are basically as follows:

1) Heater temperature requirements of 2150°F and over-temperature capability to provide maximum operational flexibility.

2) Strength coupled with ductility for ruggedness at room and elevated temperature.

3) Simplicity and reliability to assure maximum probability of success in a single design effort.

4) Stability in vacuum to avoid solid vapor interactions which may impede performance of the SiGe couples. (Similarly, the SiGe assembly must not cause degradation of the heater.)

The temperature requirement limits the materials selection to refractory metals (Ta, Cb, W, or Mo), the precious metal Pt (or near precious metal Re), and commercial refractory materials such as silicon carbide or graphite. Of these Ta, Cb, Pt, and Re couple strength and ductility for ruggedness. Cost tentatively reduces this choice further to Ta or Cb, of which Ta is the most promising with respect to possible contamination and is of higher strength. The backup selection based on a split-tube heater configuration is tungsten (using mesh instead of sheet) or Re. These would be desirable in more compromising vacuum atmospheres than anticipated in this application. Tantalum should readily accommodate vacuum environments of 10^{-4} torr for extended periods and 10^{-5} torr or less for an indefinite time.

In the various heater design possibilities considered, simplicity and reliability have historically been best achieved with the split-tube resistance element configuration. This configuration is also the most rugged, thus complementing the selection of tantalum on this basis. The split-tube is inherently advantageous in that it is self supporting from rigid power feedthroughs and operates at a lower temperature for a given heat flux. Hence, it is unencumbered by a support structure, is more compact, and is less prone to hot spots. Its inherent simplicity, ruggedness, and lower operating temperature contribute to its lower single unit cost as required in this application as well as to lower maintenance.

Split-tube heaters run at high amperage and low voltage. Hence, they are less prone to shorting due to surface contamination on the insulator, which frequently occurs in vacuum applications.

From an operational standpoint this heater also has the advantage of a readily measured end loss. The rigid power feedthroughs will be water cooled, permitting a direct calorimetric measurement of lead losses and thus enhancing the system performance analysis.

SiGe Stage Design

The SiGe module will be mounted to a cold frame which is thermally mated to the heat pipe. Because it is desirable to keep the main components of the SiGe module demountable in order to facilitate assembly and, if necessary, the replacement of components, the SiGe module will be attached mechanically rather than metallurgically to the cold frame and/or the heat pipe.

Various SiGe stage designs have been considered (Figures 1, 2, and 3). These designs are preliminary and are presented only as a representation of possible methods for mating the SiGe stage with the heat pipe.

Figure 1 shows a fixed SiGe configuration as originally prepared. The SiGe couples are mounted on an upper cylinder that is metallurgically attached to the heat pipe. This configuration is not desirable since it would not be possible to replace individual couples or a series of couples if failure occurred.

Figure 2 shows a configuration that would permit the removal of strips of SiGe couples (five couples/strip). The removal is accomplished by mounting the couples on a copper transtage which is mechanically attached to the copper cold frame. The interface between the transtage and the cold frame is coated with either zirconia or a boron nitride slurry to prevent bonding during initial test operation. The copper cold frame is metallurgically attached to the heat pipe.

Figure 3 presents a configuration which also makes use of the transtage concept; however, the SiGe couples are metallurgically banded to the transtage rather than mechanically attached as is the case with the configuration shown in Figure 2. The SiGe couples are sandwiched between an Inconel support plate and an Inconel can which surrounds the copper cold frame. This approach provides structural support of the SiGe couple strips and also provides a means for structurally mating the hot stage with the tubular module cold stage.

Each of the three concepts has several advantages and disadvantages. One primary disadvantage of the transtage approach is the number of mechanical interfaces between the components. In an attempt to limit the number of interfaces, several alternative approaches are being considered. These approaches are not defined in sufficient detail to permit inclusion in this report. One concept, however, limits the mechanical interfaces in the SiGe stage

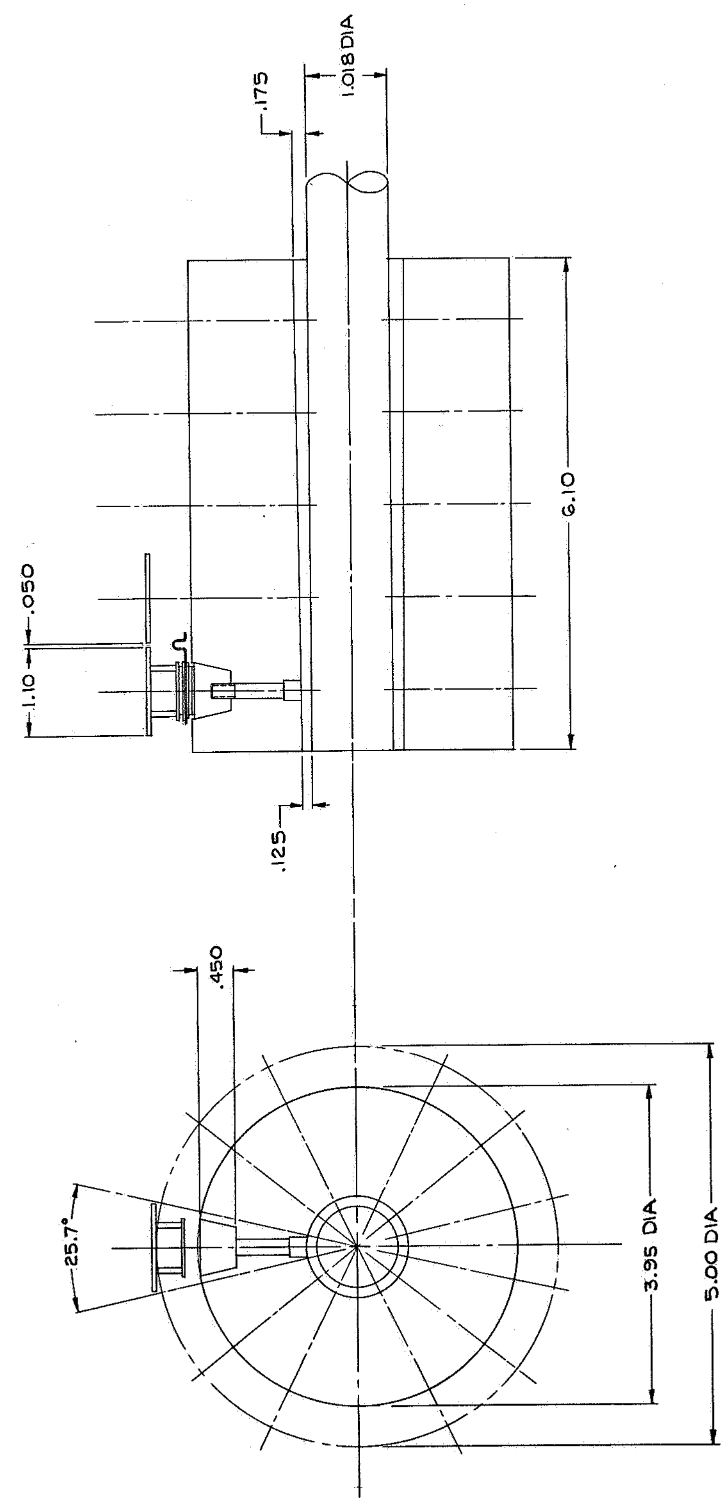

Figure 1. Preliminary SiGe Stage Design Concept 1.

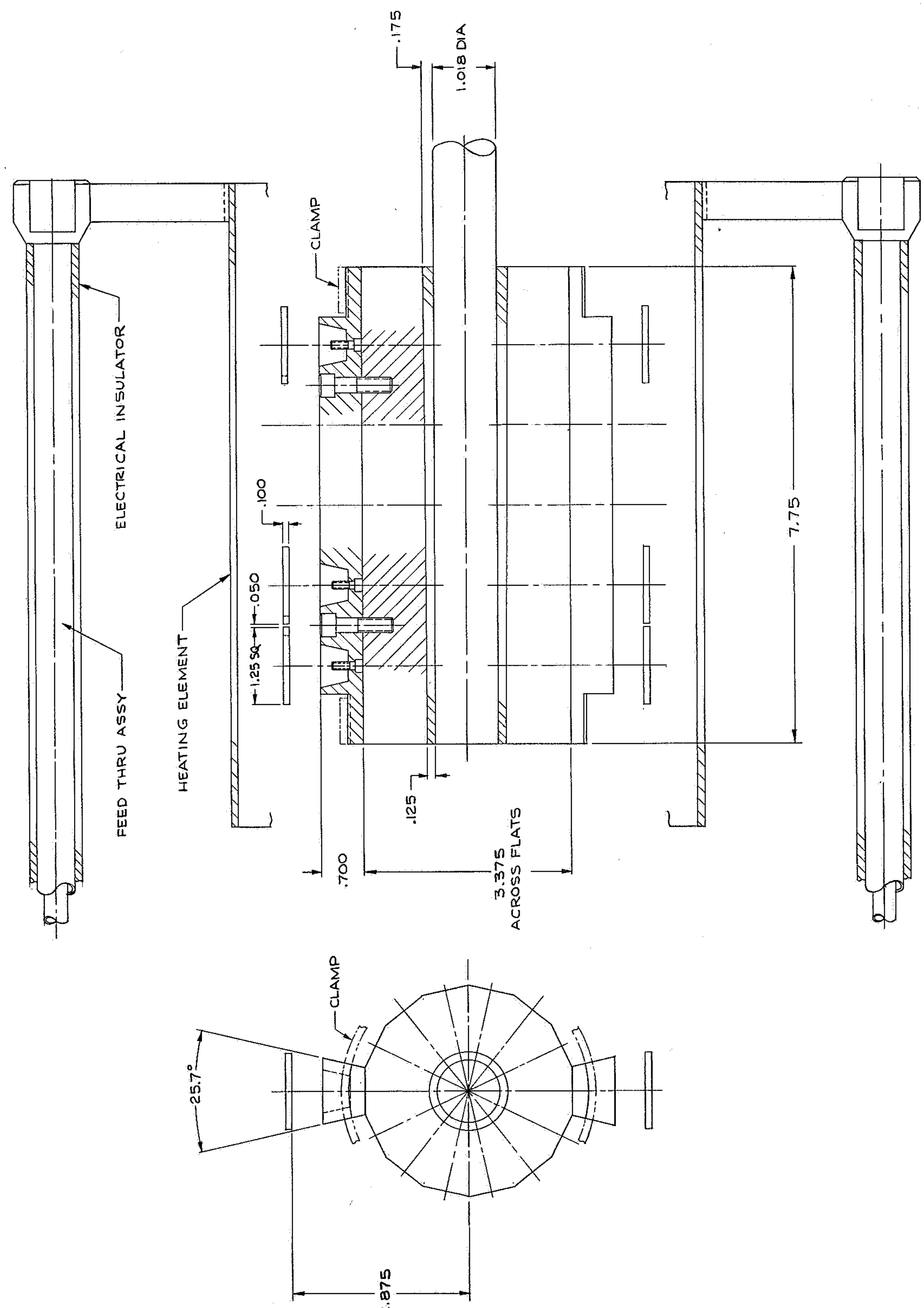

Figure 2. Preliminary SiGe Stage Design Concept 2.

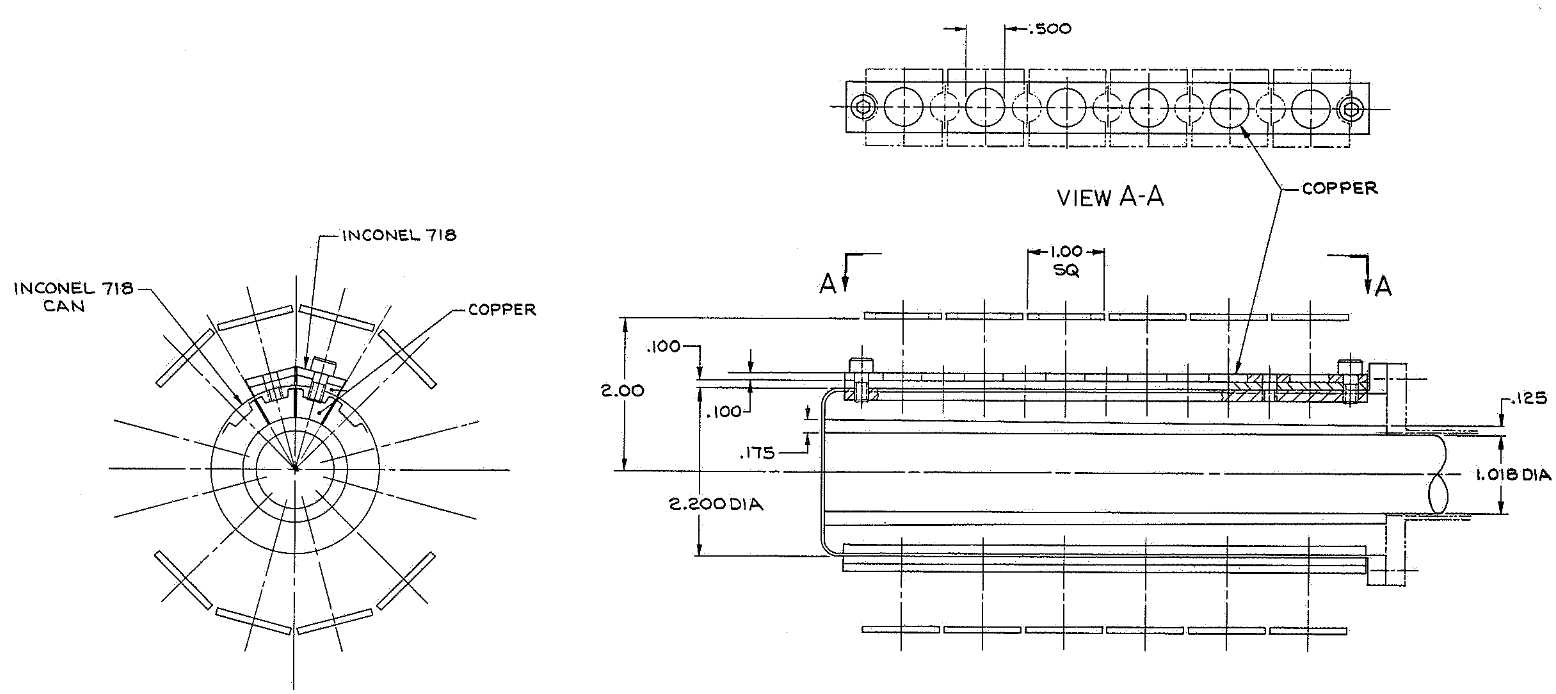

Figure 3. Preliminary SiGe Stage Design Concept 3.

to one between the cold frame and the heat pipe. The concept further modularizes the design in that the copper cold frame would be made of wedge-shaped sections that fit around the heat pipe. Because heat flow will be radial, the sectioning of the cold frame would have no effect on heat flow. Each section of the cold frame would have silicon-germanium thermocouples metallurgically attached to it along its length. The various sections would then be joined electrically at the ends.

Calorimeter Design

The calorimeter will act as the heat sink for the tubular PbTe module and will allow measurement of the heat flow through the PbTe module. The calorimeter is a split circular cylinder which will be clamped around the outer clad of the PbTe module. The calorimeter will be centered over the active portion of the module; insulation will be provided to minimize the heat flow from the module end closures to the calorimeter. Grade A aluminum silicate (made by American Lava Corporation) inserts will separate the calorimeter from the module outer clad. The mating surfaces will be coated with THERMON to provide good thermal contact. These inserts are designed to provide an outer clad temperature of about 400°F. At present the inserts have a radial thickness of about 0.3 inch. However, this value will probably change pending the results of a detailed thermal analysis of the system.

Cascaded System Performance

Preliminary performance analysis of the cascaded thermoelectric system has been completed. To avoid classification of this report, the data are not presented in detail.

Parametric performance data have been generated for both the SiGe stage and the PbTe stage. These data in conjunction with material, mechanical, and thermal considerations yield the following tentative temperature distribution for the system:

Average Heater Surface Temperature	2150°F
Average SiGe Hot Shoe Temperature	1850°F
Average SiGe Cold Strap Temperature	1150 - 1200°F
Average PbTe Inner Clad Temperature	1050 - 1100°F
Average PbTe Outer Clad Temperature	400°F

The range indicated for the SiGe cold strap temperature is based on preliminary designs considered thus far; the operating value will depend upon the final element configuration and the results of detailed thermal analysis of the interstage connecting the SiGe module to the heat pipe. Similar analysis is required before the inner clad temperature of the PbTe module can be further defined.

The overall efficiency of the cascaded thermoelectric test generator is indicated in Figure 4 for a range of tubular PbTe module hot side operating temperatures. The data are based on the temperature profiles presented above, estimates of the heat loss through the coupling of the SiGe and PbTe modules, and on the assumption that all of the heat generated in the active portion of the electrical heater is transferred to the SiGe hot shoes. The values presented will be adjusted as required during the remainder of the Phase I design effort.

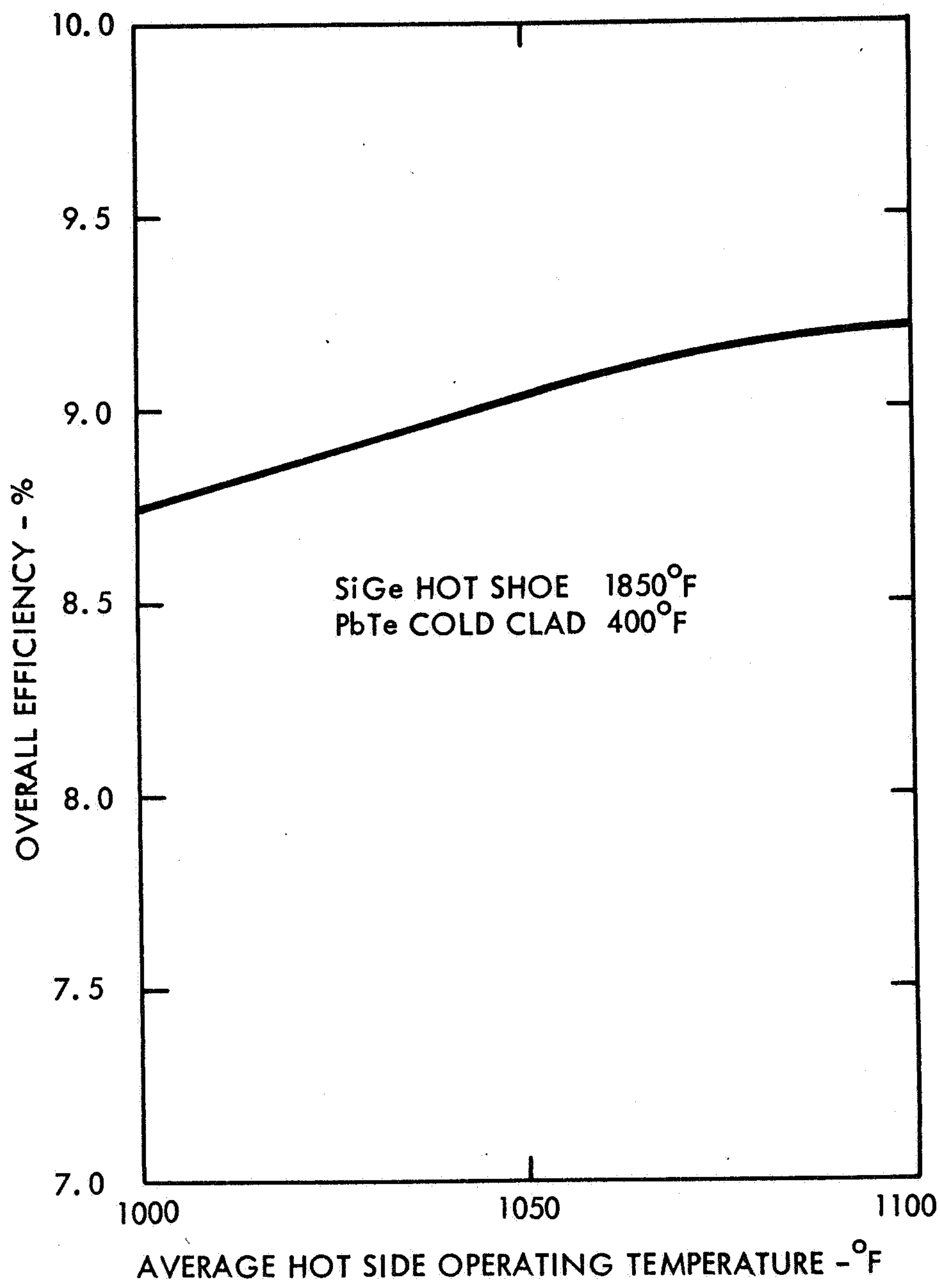

Figure 4. Cascaded Thermoelectric System Overall Efficiency Versus Tubular Module Average Hot Side Operating Temperature